International Journal of Environment, Ecology, Family and Urban Studies (IJEEFUS)
ISSN (P): 2250-0065; ISSN (E): 2321-0109
Vol. 9, Issue 1, Feb 2019, 53-70

TRANS STELLAR
•Journal Publications •Research Consultancy

Original Article

A SEASONAL CHANGE IN PHYSICOCHEMICAL, BACTERIOLOGICAL PARAMETERS AND MACROINVERTEBRATE ASSEMBLAGE STRUCTURE AND COMPOSITION IN MIKENO SECTOR, EASTERN DRC

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ABSTRACT

Water resource contamination is still a major concern in several regions of developing countries, especially in the Democratic Republic of Congo (DRC) in which polluted waters poses serious risks to human health and the environment. The aim of this study was to assess the inter-annual and seasonal changes in physicochemical, bacteriological parameters and community composition of macroinvertebrates in the rivers in Mikeno sector. The physicochemical parameters analysed, including pH, temperature, electrical conductivity, total dissolved solid, total suspend sediment, dissolved oxygen, biological oxygen demand after 5 day incubation, chemical oxygen demand, alkalinity, total hardness, calcium hardness, magnesium hardness, chloride, sulphate, total phosphorus, soluble reactive phosphorus, total nitrogen, ammonia, nitrate and trace of heavy metals collected from rivers and springs in Mikeno sector using standards methods for water analysis during the period of two years (2015- 2016). The results indicate the annual and seasonal difference in the physicochemical composition of water. All physicochemical values in general, analysed in the springs and rivers were low during the sampling period in the two years. Water analysed during the two seasons appear to meet drinking water standards, according to the WHO guidelines. But for bacteriological aspect some springs contained a high coliform count and need to have specific treatment before to be used for drinking. Rwinkwi River had a high species richness with 19 taxa and Nyabisika River was poor in macroinvertebrate. This study is important for the present situation and can be applied in similar environmental compartments in the future to assess the availability of safe drinking water in developing countries.

KEYWORDS: Seasonal, Physicochemical, Bacteriological, Macroinvertebrates & Mikeno Sector

Received: Oct 02, 2018; **Accepted:** Oct 22, 2018; **Published:** Jan 23, 2019; **Paper Id.:** IJEEFUSFEB20198

1. INTRODUCTION

The quality of surface water is a very sensitive problem currently in the world. The increased demand for water from the growing population in the recent decades poses various problems, both qualitatively and quantitatively (Ramdani *et al.*, 2012). Water is an essential ingredient for the maintenance of life, safe and healthy environment for aquatic biodiversity (Hassan *et al.*, 2016). The importance of access to safe drinking water and effective sanitation is fundamental to any transformation of development and linked to the overall achievement of

the Sustainable Development Goals (SDGs).

Rivers and springs water are vital and vulnerable freshwater ecosystems are critical for the sustenance of all life. They play a major role in controlling the global water cycle and in the hydrologic cycle. They are the most dynamic agents of transport (Dalai *et al.*, 2004). However, the declining water quality of these ecological systems threatens their sustainability and is therefore a matter of serious concern. The quality of water may be described according to their physicochemical and microbiological characteristics (Shah *et al.*, 2007), but also macroinvertebrates assemblages (Azrina *et al.*, 2006; Mariadoss and Ricardo, 2015). Environmental variability in time and space is known to shape the distribution of organisms, their interactions and their adaptations (Wiens, 1986). Such spatio-temporal variability is a basic characteristic of running water systems. However, the surface water quality is deteriorating due to anthropogenic activities, industrialization, farming activities, transportation, urbanization, animal and human excretions and domestic wastes (Gaur *et al.*, 2005). It is a common practice for people living along the river catchments to discharge their domestic waste as well as human excreta into rivers. Wild and domestic animals using the same drinking water can also contaminate the water through direct defecation and urination. The biodiversity composition and richness of most of the Earth's major ecosystems are changing as a result of harvesting, habitat destruction, pollution, exotic invasions, and climate change (Uwadiae *et al.*, 2012).

Variation in the quality and quantity of river water due to natural and anthropogenic activities is widely studied in the case of several world rivers (Gupta *et al.*, 2011; Srivastava *et al.*, 2011; Jena *et al.*, 2013). The interactions of both the physical and chemical properties of water play a significant role in composition, distribution and abundance of aquatic organisms (Gangwara *et al.*, 2012). Most interestingly, freshwater macroinvertebrate species vary in sensitivity to organic pollution and, thus, their relative abundances have been used to make inferences about pollution loads. In natural pristine rivers, high diversity and richness of species could be found (Armitage *et al.*, 1983). The anthropogenic impacts on water quality and the distribution and diversity of macroinvertebrates had been reported in the literature (Nedeau *et al.*, 2003).

Water quality in rivers is an important problem for water environment management and for population using water for their daily activities. High discharge events and physicochemical change of water quality can cause severe population losses and changes in the community composition and structure (Lytle *et al.*, 2008; Mesa, 2012). This temporal variability has great influence on the emergence, reproduction, growth and development of aquatic macroinvertebrates and the seasonal replacement of the organisms (Bogan and Lytle, 2007). The spatial temporal distribution of water quality could provide dynamic information for the decision maker of water environment management (Yel *et al.*, 2003; Xu *et al.*, 2012). It is necessary to properly evaluate the spatial and temporal pattern of water quality in rivers and springs.

Spatio-temporal variation analysis of water quality, macroinvertebrate species and identification of water pollution sources in the Mikeno sector watershed is very important for water resources protection and sustainable utilization. Then, Greater Virunga Transboundary Collaboration (GVTC) undertook a hydrological study in the Virunga massif (Mikeno sector of PNVi (Parc National des Virunga), Volcano National Park and Mugahinga Gorilla National Park) to understand the water scarcity and associated conflicts in the Greater Virunga.

The aim of the research presented in this paper is to assess the level of physicochemical, microbiological parameters and heavy metals in water, which are important in the evaluation of drinking water quality (WHO, 2011) and macroinvertebrates assemblage structure and composition. The assessment was based on water physicochemical characterization including pH, electrical conductivity, dissolved oxygen, some soluble ions and toxic metal such as Cr, Ni,

Cu, Zn, Hg, Cd, Se, Fe and Pb. Microbiological assessment was based on germs such as Klesbiella, Enterobacteria, *Escherichia coli*, Hafnia, Serratia, Citrobacteria, Salmonella, Shigella, and *Vibrio cholera*. Then the macroinvertebrate assemblage concerned all aquatic macroinvertebrates contained in rivers and streams. Water samples were taken in both the dry and wet seasons during two years (2015 – 2016) and analysed to identify whether or not there were any changes in water quality with the season.

2. MATERIAL AND METHODS

2.1. Description of Sampling Sites

The assessment was carried out, in and around Virunga National Park in Mikeno Sector, within the Virunga landscape. The assessments were restricted to water points considered during the previous hydrological study in the Virunga massif (Karume *et al.*, 2016). These include Kabaya source, Kabaya River, Rwankwi River, Indata River, Rutshuru River, Kamira River, Kamira source, Kiwerha source, Kiwerha River, Kanyamarebe source, Kanyamarebe River, Rutshuru River (inlet), Nyabisika source and Nyabisika River. The same water sampling points used during rain and dry seasons 2015 were used during 2016 for monitoring water quality and quantity in Mikeno sector and macroinvertebrate assemblage. The figure 1 presents the localization of sampling points in Mikeno sector.

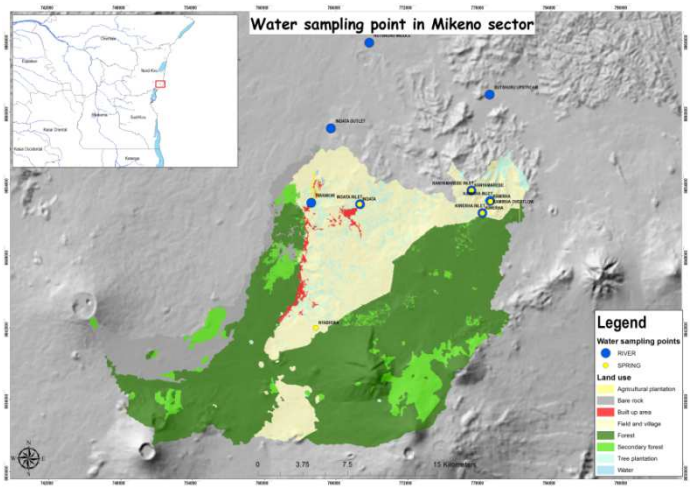

Figure 1: Map Showing the Sampling Points in Mikeno Sector

2.2. Sampling and Physicochemical Analysis of Water

Based on the type of water source, two methods were used to determine the quantity of water at the sampling source. For a river, discharge was measured by determining the velocity of a floating object and the total cross-sectional area of the river following the Floating Method procedure (Bartram and Ballance 1996; Bagalwa *et al.*, 2012). For source and borehole, bucket and stopwatch method were used. Very easy method to estimate discharge by simply measuring the time it takes to fill a container of a known volume. This method only works for systems with fairly low flow volume. A bucket of 10 liters was placed underneath to capture all the discharge and a stopwatch was used to estimate the time necessary to fill the bucket (Michaud and Wierenga, 2005). Three measurements were done for each source, borehole and a river.

For water quality, surface water temperature, pH, Electrical Conductivity, Total Dissolved Solid, Dissolved Oxygen (DO), five-day Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Hardness, Calcium

hardness, Magnesium hardness, Calcium, Magnesium, Chloride, Sulphate, Alkalinity, Total phosphorus, soluble reactive phosphorus, Total nitrogen, Ammonium, Nitrate and TSS were measured. The analysis followed the procedures described in Golterman *et al.* (1978); APHA (2006); Wetzel and Liken (2000).

Samples were collected during different times of the day. Water was collected at a depth of 30 cm, near midstream. The temperature, pH was measured using a YSI PROFESSIONAL PLUS. The meter sensor was dipped into the water and the temperature reading was recorded after the meter had stabilized. At each sampling point, two water samples were collected in prewashed glass bottles. Concentration of DO in the water was determined after fixation in the field, following the iodometric Winkler's method (Golterman *et al.*, 1978; Olapande and Omitoyin, 2012). BOD_5 was measured as the decrease in DO after incubation in the dark at 20°C for five days (Olapande, 2011). Other water samples were taken in plastic bottles at the same time, for other chemical analyses (heavy metals). The plastic bottles were rinsed before overnight with 1M HCl and then with distilled water. All measurements were made in duplicate. Data were compared with UNECE (1994); FEPA, (1991) and WHO (1993) standards.

2.3. Sampling and Heavy Metal Analysis of Water

For heavy metal variables relevant to human health such as Hg, Cd, Fe, Zn, Pb, Ni, Cr, Se in water samples were delivered to the INES laboratory in Musanze for analysis. Analyses were conducted using direct determination by flame atomic absorption spectrometry as described in ISO 8288 (ISO, 1986)

2.4. Sampling and Bacteriological Analysis of Water

Samples were collected in clean, sterile polypropylene 200 ml bottles. Before the bottles were washed with deionized water and sterilized in the oven at 60 °C overnight. At the field, bottles were washed thrice before collecting sample. All samples were kept in a refrigerated cool box and transported to the laboratory. All analyses were completed at the Laboratory of Bacteriology at Goma Volcano Observatory. Analyses for total coliform, faecal coliform and faecal streptococci were made in accordance with standard methods (APHA, 1995). Nutrient agars (NA), Salmonella- shigella agar, Thiosulphate citrate bile salt sucrose agar were used to determine heterotrophic bacterial, Salmonella and Shigella, *Vibrio cholera* respectively. Isolates were confirmed by some conventional biochemical test (SCA, 2002).

2.5. Macroinvertebrate Sampling and Analysis

The benthic macro-invertebrates were collected using a standard form hand-net of 30 cm wide, 20 cm high and 50 cm long with mesh size of 500 μm. They were collected along the river stretch in a stream direction with an effective sampling effort of 10 minutes per person (Olivier and Scheiderman, 1956). The presence of stones in the riverbed and water plants were taken in the hand-net and washed in a bucket to collect macro-invertebrate attached. The collected organisms were stored and preserved in formalin 4 % on the field. Identification was made at the malacology laboratory of up to the species level when possible using the keys of determination of Needhan and Needham, (1962) and Micha and Noiset, (1982). If the species were not found in the key, the identification was restricted to the family or genus level.

2.6. Statistical Analysis

Pass 18 was used to compare the seasonality and annual physicochemical, bacteriological parameters in the different sampling sites in Mikeno sector. T-test and ANOVA one way was used to compare the statistic difference between the parameters.

3. RESULTS AND DISCUSSIONS

3.1. Water Quality Trends

Seasonal change of water quality during the 4 seasons (2015 and 2016) in the Mikeno sector, in the Greater Virunga Landscape was assessed in 6 springs and 8 rivers and streams in the sector. Results of physicochemical analysis of the water samples collected in springs used for drinking by the population are presented in table 1.

Table 1: Seasonal Variation of Mean Physicochemical Characteristics of Springs in Mikeno Sector

	Season	Indata	Kamira	Kamira Overflow	Kiwerha	Kanyamarembe	Nyabisika	Standards for Drinking*
Alkalinity (mg/L)	Rainy	62	22	19	17	15	18	100 - 600
	Dry	212	68	72	60	60	24	
Calcium (mg/L)	Rainy	2.01	0.89	0.78	1.45	0.89	0.45	75
	Dry	6.30	3.15	3.15	2.86	4.30	2.86	
Calcium Hardness (^oF)	Rainy	5.03	2.23	1.96	3.63	2.23	1.12	20 – 50
	Dry	15.75	7.88	7.88	7.16	10.74	7.16	
Chloride (mg/L)	Rainy	48	56	60	72	72	48	200 - 250
	Dry	44	36	36	44	56	40	
COD (mg/L)	Rainy	6.8	19.6	12.4	7.6	20.4	13.2	-
	Dry	6.8	6.8	6	4.8	3.6	4.4	
Discharge (m^3/s)	Rainy	0.012	0.001	-	0.0019	0.0003	0.00019	-
	Dry	0.006	0.001	0.0002	0.0018	0.0006	0.00009	
DO (mg/L)	Rainy	7	6.5	5.25	6.5	6.6	5.1	4.92 - 6.33
	Dry	5.6	4.6	5	5.8	5	9	
EC (µS/cm)	Rainy	709	202	208.5	197	182.9	125	200
	Dry	774	228	235	225	211	158	
Magnesium (mg/L)	Rainy	1.27	1.41	2.28	2.82	1.61	1.74	30
	Dry	6.01	3.17	0.07	1.22	1.34	0.24	
Magnesium Hardness (^oF)	Rainy	5.31	5.87	9.5	11.73	6.7	7.26	30
	Dry	25.05	13.20	0.28	5.08	5.58	1	
NH_4^+ (µmol/L)	Rainy	0.06	0.49	0.69	0.61	0.69	0.57	-
	Dry	3.22	1.09	3.05	2.93	2.46	3.99	
NO_3^- (µmol/L)	Rainy	0.04	0.07	0.1	0.08	0.13	0.11	45
	Dry	30.98	14.21	14.45	17.41	24.05	24.72	
pH	Rainy	6.92	7.2	6.98	7.01	7.22	7.48	6.5 – 8.5
	Dry	6.81	7.68	7.75	7.75	7.92	8.33	
SRP (µmol/L)	Rainy	0.58	0.17	0.35	0.42	0.44	0.27	-
	Dry	0.53	0.32	0.49	0.56	0.59	0.28	
Sulfate (mg/L)	Rainy	119.04	176.64	180.48	161.28	96	138.24	250 – 400
	Dry	261.12	99.84	49.92	53.76	53.76	96	
TDS (mg/L)	Rainy	354.5	101	104.25	98.5	91.45	62.5	500
	Dry	387	114	118	112	106	78	
Temperature (^oC)	Rainy	17.1	17.5	17.5	17.2	18.4	17.2	26.6
	Dry	19.3	17.8	17.8	18	19.2	19.6	
TN (µmol/L)	Rainy	1.96	3.74	5.34	4.67	7.42	6.36	-
	Dry	33.78	14.83	16.98	19.92	25.82	28.24	
Total Hardness (^oF)	Rainy	10.34	8.1	11.45	15.36	8.94	8.38	300
	Dry	40.8	21.08	8.16	12.24	16.32	8.16	
TP (µmol/L)	Rainy	0.61	0.28	0.52	0.52	0.57	0.3	-
	Dry	0.54	0.36	0.5	0.67	0.59	0.32	
TSS (mg/L)	Rainy	0.04	0.04	0.04	0.04	0.04	0.04	500
	Dry	0.06	0.193	0.186	0.193	0.195	0.08	

*** Limit recommended by World Health Organization (WHO, 2011) Guidelines for Drinking-water Quality**

The temperature varied seasonally from all the sampling springs, but statistically the difference is not significant ($p > 0.05$). The highest value of water temperature was recorded in dry season at Nyabisika spring (19.6 °C) and the lowest value was recorded in rainy season in Indata spring (17.1 °C). The previous study carried out by other authors in the city of

Kinshasa and Kikwit demonstrated that the monthly average temperature varied from 25.0 to 26.8 °C in the dry season and from 26.5 to 30.7 °C during the wet season (Kapembo *et al.*, 2016; Nienie *et al.*, 2017). These results are comparable with other published data obtained in similar sites under tropical conditions (Nola *et al.*, 2013). The values recorded during the two seasons are between the WHO standards for drinking water (WHO, 2004).

pH is an important operational water quality parameter. In the aquatic ecosystem, pH influences the solubility of toxic metals, which can have a negative effect on aquatic living organisms and human health. As for temperature, the highest value of pH was recorded in Nyabisika spring in rainy season and the lowest in Indata spring in dry season. In general, in the study area, all pH values recorded during the period were ranging between 6.5 and 8.5 as recommended by the WHO standards for drinking water (WHO, 2004). The geology of sampling sites could possibly be responsible for the final pH recorded in the spring.

EC is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions; on their total concentration, mobility, and valence; and on the temperature of measurement. Increasing levels of electrical conductivity are due to the decomposition and mineralization of organic materials (Abida, 2008). EC for all springs were higher (>200 µS/cm) than the values recommended by WHO (2011), except Nyabisika, Kiwerha and Kanyamarebe springs in Dry season and Nyabisika in rain season. The highest values of EC were recorded in Indata spring in the two seasons (774 and 709 µS/cm) respectively in Dry and rainy season. TDS values in all the springs are low during the sampling period throughout the two seasons, showing the turbidity value being less than 5NTU, however, the water for these springs are suitable for human consumption (WHO, 2004).

DO is one of the important parameters in water quality assessment (Bagalwa *et al.*, 2014). The concentration of DO during the rainy and dry seasons is within the recommended WHO limit except for the Kamira spring where a value of 4.6 mg/L was recorded in dry season. However, highest O_2 value was found during the dry season in Nyabisika 9 mg/L. These results agree with a recent study of Ali *et al.*, (2016) performed under tropical conditions. Total Hardness varied from 8.10 – 40.8 ^oF in Kamira spring in rainy season and Indata spring in dry season respectively. According to the classification of hardness of water (WHO, 2011), the spring water of Mikeno sector can be classified as moderately hard to very hard. The American Water Works Association indicates that ideal quality water should not contain more than 80 mg/L of total hardness as $CaCO_3$. However, High levels of total hardness are not considered a health concern. The values obtained in the Mikeno sector for total hardness are within the WHO guideline for drinking water (WHO, 2011) except the Indata spring in dry season. On the contrary, calcium is an important component of the cell walls of aquatic plants, and of the bones or shells of aquatic organisms. Magnesium is an essential nutrient for plants, and is a component of chlorophyll. The values recorded in this study showed a variation during the seasons. Calcium hardness varied from 1.12 to 15.5 ^oF in rainy season in Nyabisika spring and dry season in Indata spring respectively. For magnesium hardness the lowest value was recorded in dry season in Kamira overflow (0.27 ^oF) and the highest value was recorded in dry season in Indata spring (25.05 ^oF). This was similar for calcium and magnesium in the same springs.

Alkalinity varied also from one site to another. The highest value was recorded at the Indata spring (212 mg/L) and the lowest at Kanyamarebe spring (15 mg/L) in the dry season during the study period. The concentrations of dissolved ions, cations (NH_4^+), and anions (Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}) in water samples from the springs as shown in Table 1 varied from sites and seasons. These ions were found to be present in lower concentrations in spring during the sampling period. The concentration of these substances in the spring water was between the standards suggested by WHO for

drinking water (WHO, 2011). The concentration of dissolved ions does not follow a specific seasonal trend. In general, the results show that the concentration of all analysed dissolved ions in water samples from wells and rivers during both seasons falls below the permissible limit of the WHO recommendation for drinking water and domestic purposes (WHO, 2011). However, Indata has recorded lowest value in term of total nitrogen.

Results of physicochemical analysis of the water samples collected in rivers and streams in the Mikeno sector, in the Greater Virunga Landscape are presented in table 2.

Table 2: Seasonal Variation of Mean Physicochemical Characteristics of Water in Rivers and Streams in Mikeno Sector

	Season	Indata Inlet	Rwankwi	Idanta Outlet	Rutshuru Middle	Rutshuru Upstream	Kamirha	Kiwerha	Kanyamarebe	Standards
Alkalinity (mg/L)	Rainy	70	59	57	49	28	30	16	24	100 – 600
	Dry	ND	204	204	212	92	76	56	76	
BOD_5 (mg/L)	Rainy	6.6	14.4	15.4	8	7.8	21.2	27.4	24	0 - 5.0
	Dry	ND	3.4	1.6	2.2	3	2.6	ND	2.6	
Calcium (mg/L)	Rainy	1.68	3.13	1.45	0.89	1.23	0.34	0.78	0.78	75
	Dry	ND	5.44	5.73	4.30	3.44	3.44	3.15	3.15	
Calcium Hardness (mg/L)	Rainy	16.8	31.3	14.5	8.9	12.3	3.4	7.8	7.8	20 – 50
	Dry	ND	54.5	57.3	43.0	34.4	34.4	31.6	31.6	
Chloride (mg/L)	Rainy	48	64	68	108	100	64	48	52	250
	Dry	ND	40	32	52	36	36	28	36	
COD (mg/L)	Rainy	7.6	8.4	2.8	13.2	13.2	12.4	18	16.4	-
	Dry	ND	5.6	3.2	4.8	4.8	4	4.4	0.4	
Discharge (m^3/s)	Rainy	0.37	1.27	1	29.8	28.15	0.031	0.001	0.0002	-
	Dry	0.16	0.59	2.89	25.71	23.99	0.001	0.7	0.0006	
DO (mg/L)	Rainy	4.7	6.9	10.5	7.2	8.4	6.2	7.9	6	4.96 – 6.33
	Dry	4.6	4.4	4.4	4.6	6	4.8	5.6	4.4	
EC (µS/cm)	Rainy	714	627	676	561	294	207	193.7	181.2	200
	Dry	776	717	687	678	678	235	220	208	
Magnesium (mg/L)	Rainy	14.93	18.99	4.76	21.03	4.76	25.11	16.95	18.31	30
	Dry	ND	1.75	3.20	11.90	10.51	22.07	22.14	13.89	
Magnesium Hardness (mg/L)	Rainy	6.15	7.82	1.96	8.66	1.96	10.34	6.98	7.54	30
	Dry	ND	0.72	1.32	4.90	4.33	9.09	9.12	5.72	
NH_4^+ (µmol/L)	Rainy	0.07	0.04	0.28	0.34	0.65	0.46	0.59	0.76	
	Dry	ND	3.38	2.22	1.5	1.44	1.51	3.12	1.22	
NO_3^- (µmol/L)	Rainy	0.06	0.11	0.09	0.09	0.16	0.1	0.1	0.14	45
	Dry	ND	18.54	23.61	16.91	18.77	10.91	20.77	14.94	
pH	Rainy	6.15	7.65	7.37	7.56	7.7	7.5	7.29	7.31	6.5 – 8.5
	Dry	6.89	8.66	8.82	8.55	8.52	8.07	8.36	8.02	
SRP (µmol/L)	Rainy	0.61	0.52	0.5	0.15	0.07	0.52	0.35	0.48	-
	Dry	ND	0.48	0.44	0.25	0.16	0.36	0.46	0.56	
Sulfate (mg/L)	Rainy	138.24	245.76	84.48	92.16	126.72	157.44	142.08	172.8	150
	Dry	ND	80.64	119.04	130.56	107.52	107.52	92.16	84.48	
TDS (mg/L)	Rainy	357	313.5	338	280.5	147	103.5	96.85	90.6	500
	Dry	387	359	343	339	355	117	110	104	
Temperature (°C)	Rainy	17.2	19.9	18.3	21.8	21	17.6	18.3	19.6	26.6
	Dry	19.4	22	19.9	21.3	20.2	18.2	18.9	19.1	
TN (µmol/L)	Rainy	3.09	6.29	5.12	5.27	9.08	5.85	5.3	7.97	-
	Dry	ND	21.18	25.36	17.93	19.73	12.05	23.21	15.32	
Total Hardness (mg/L)	Rainy	103.4	156.4	55.9	108.9	50.3	111.7	89.4	95	300
	Dry	ND	143.2	156.4	156.4	129.2	176.8	170	136	
TP (µmol/L)	Rainy	0.57	0.87	0.55	0.3	0.43	0.53	0.43	0.66	-
	Dry	ND	0.5	0.49	0.3	0.17	0.48	0.51	0.69	
TSS (mg/L)	Rainy	0.12	0.16	0.16	0.32	0.16	0.08	0.04	0.12	500
	Dry	ND	0.20	0.20	0.20	0.23	0.22	0.19	0.11	

Physicochemical parameters vary from one season to the other. The results of different sites presented in these tables (Table 1 and table 2) show that the temperature is high in river Indata Lime (21.8 ^oC) and low in Indata source (17.1^oC). This temperature has increased in general in some sites compared to the previous sampling in rainy season of 2015 (16 to 20 ^oC). The high temperatures recorded in some sites are probably due to the vegetation cutting near the water body. The fluctuation in river water temperature usually depends on the season, geographic location, sampling time and temperature of effluents entering the stream (Ahipathy, 2006).

In general, the temperature was higher in 2016 than in 2015 in many sites investigated. The high temperature value was probably due to the vegetation cut near sampling sites and also the erosion occurring during the rainy season between the two periods of study.

In the different samples, pH varied from 6.15 to 7.65. The highest pH was recorded in the river Indata Lime and the lowest pH at the site of Indata River. These values of pH are high compared to the data recorded in rainy season in 2015 in the same sites. pH recorded during the sampling period in the different sites are within the WHO standards range (WHO, 2004) and with the data in the watershed, obtained by other authors (Mbalassa *et al.*, 2014).

DO varied in the different sampling sites. The highest DO concentration was recorded in the river Rwanki and the lowest DO in the river Indata. Comparatively to previous data from rainy season from 2015 (5.42 to 7.78 mg/L), an increase/or a decrease of DO is observed in some sites (4.7 to 10.5 mg/L). This was probably due to the erosion occurring near and in the sites, which brought material excess in the water body. DO is higher than 6 mg/L except in the sampling site of Indata River (4.7 mg/L). The highest values recorded in the sampling sites were also reported by Karume *et al.*, (2016) in the Greater Virunga Landscape. The high velocity and low temperature (> 22^{o}C) are the reasons why the DO is high in the sites.

This is also, confirmed by the results of BOD_5 and COD. COD is the amount of oxygen consumed during the chemical oxidation of organic matter using strong oxidizing agent like acidified potassium dichromate. The COD is linked with heavy pollution. It is commonly used to indirectly measure the number of organic compounds in water. The measure of COD determines the quantities of organic matter found in water. This makes COD useful as an indicator of organic pollution in surface water (Faith, 2006). COD is ranged between 2.8 and 20.4 mg/L in the sampling sites. BOD_5 is a measure of the oxygen in the water that is required by the aerobic organisms. It is the amount of oxygen required by the bacteria in stabilizing the decomposable organic matter. The aim of BOD_5 test is to determine the amount of bio-chemically oxidizable carbonaceous matter (Gupta *et al.*, 2003). The bio-degradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Abida, 2008). BOD_5 directly affects the amount of dissolved oxygen in rivers. The greater the BOD_5, the more rapidly oxygen is depleted in the river. Sources of BOD_5 include leaves and woody debris; dead plants and animals; animal manure; faecal matter and urban storm water runoff (USEPA, 1997). BOD_5 from rivers in the study area was about 6.6 to 27.4 mg/L. compared to previous data from rain season in 2015, the COD has decreased and BOD_5 has increased due to the same raisons evoked before.

The highest EC was recorded at the river Indata (714 µS/cm) and the lowest electrical conductibility at the river Kabareberebe. This was also observed in the previous samples in 2015. High EC indicates a large quantity of dissolved minerals, salt, thereby making it sour and unsuitable for drinking (Srivastava and Sinha, 1996). The maximum permissible limit of this parameter for drinking water is 300µS/cm. However, the average specific conductivity exceeds this limit because of its high values during rainy season. This was also observed by Jayaseelan *et al.*, (2015) in Tamil Nadu in India. The lowest value recorded in rainy season is due to the floods and rain water, which contains more electrolytes and reduces the EC in running water.

The same observation was also found with TDS data. TDS is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro granular suspended form. The permissible limit of TDS of drinking water is 500 mg/l (WHO, 2004). TDS is high in the rivers and streams in the Mikeno sector during the dry season. The highest value (387 mg/L) of TDS was recorded at Indata inlet site while the lowest value (84.48 mg/L) was recorded at the Kanyamarebe site. The observation shows that the TDS is within the permissible range as prescribed by WHO (2004) in the rivers and streams in Mikeno sector. These changes in water quality may be attributed to the local climatic conditions and water exchange mechanisms. But, the values were in the range of standard water quality for

drinking (WHO, 2004). It is known that the quality of surface water within a region is governed by both natural processes (such as precipitation rate, weathering processes and soil erosion) and anthropogenic effects (such as urban, industrial and agricultural activities and human exploitation of water resources) (Shetty *et al.*, 2013).

The values of total alkalinity were comparatively moderate. The highest values were recorded in dry season in all rivers and streams. The water for domestic use having alkalinity less than 100 mg/l is safe. The values obtained for the Mikeno sector are low than the values recorded by Saravana *et al.*, (2011) in Tamil Nadu in India.

Total hardness was found in the sample water ranges from 50-177 mg/l, which shows that water is safe for drinking purpose. Hardness has no known adverse effects on health. However, maximum permissible level prescribed by WHO for drinking water is 300 mg/l. According to some classifications, water having hardness up to 75 mg/l is classified as soft, 76-150 mg/l is moderately soft, 151-300 mg/l as hard (Dufor and Becker, 1964) and more than 300 mg/l as very hard. On this basis, the results show that all the samples were moderately soft except sample Rwanki (156.4 mg/L) in rainy season (Ravisankar and Poogothai, 2008) and for Idanta outlet, Rutshuru middle (156.4 mg/L), Kamirha (176.8 mg/L) and Kiwerha (170 mg/L) in the dry season.

The chloride content of the water samples was low in rainy season. According to WHO, the maximum permissible limit for chloride is 250 mg/l. Chloride varied from 28 – 108 mg/L in all the sampling sites. The value observed in the present study is in the range of permissible limit (Ravisankar and Poogothai, 2008).

The sulphate content varies between 81 to 246 mg/l. It doesn't have a specific seasonal trend in the sampling sites on rivers and streams in Mikeno sector. Some sampling sites have high values in dry season and others in rainy season. This was also noted in the values recorded for TSS in different samples. Sulphate values were also found to be within the prescribed limits.

Total hardness (5.03 – 15.36 ^{o}F), calcium hardness (1.12 – 7.82 ^{o}F), magnesium hardness (1.96 – 11.73 ^{o}F), alkalinity (15 – 70 mg/L), chloride (48 – 108 mg/L) and sulphate (84.48 – 245.76 mg/L) varied also from one site to another. Compared to previous data from rain season in 2015, total hardness, calcium hardness, alkalinity has decreased where magnesium hardness has increased and chloride, sulphate has less fluctuated in some sites. Man and animals excrete high quantities of chloride; therefore it indicates sewage contamination (Sangpal *et al.*, 2011). The alkalinity of natural water is due primarily to the salts of weak acids, although weak or strong bases may also contribute. Bicarbonate represents the major form of alkalinity, with that carbonate and hydroxide alkalinity also. But all these concentrations of different chemicals are within the WHO standards. TSS varied from sites to sites and from one period rainy season 2015 to one season 2016.

Total phosphorus (0.28 – 0.87 µmole/L), soluble reactive phosphorus (0.07 – 0.58 µmole/L), total nitrogen (1.96 – 9.08 µmole/L), ammonia (0.04 – 0.76 µmole/L) and nitrate (0.04 – 0.16 µmole/L) are low in all the samples and the results showed that most of the measured values of these parameters are within the WHO guidelines for drinking water quality (WHO, 2004). Nutrients in general varied from site to site and from season to season. The ammonia nitrogen concentrations varied from 0.25 - 8.14 mg/L, the concentrations of total phosphorus ranged from 0.035- 0.665 mg/L. But we can observe an increase compared to data from previous data during rainy season in 2015 for both TP and TN.

3.2. Bacteriological Aspects

The results for bacteriology of water samples at different sampling sites collected in the 2016 rainy season are presented in table 3.

Table 3: Bacteriology Result in Rain and Dry Season in Mikeno Sector

	Season	Klesbiella	Enterobacter	E. coli	Hafnia	Serratia	Citrobacter	Salmonella & Shigella	Vibrio Cholerae
Indata spring	Rainy	1400	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Indata inlet river	Rainy	8000	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Indata outlet river	Rainy	2400	4200	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Kamirha inlet river	Rainy	0	4400	0	0	0	0	0	0
	Dry	1300	0	0	0	0	0	0	0
Kamirha outflow reservoir	Rainy	0	3200	1600	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Kamirha spring	Rainy	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Kanyamarebe inlet river	Rainy	5400	0	0	2000	0	0	0	0
	Dry	0	0	2500	0	0	1300	0	0
Kanyamarebe spring	Rainy	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Kiwerha inlet river	Rainy	4600	4400	0	0	0	0	0	0
	Dry	0	0	1300	0	0	0	0	0
Kiwerha spring	Rainy	0	1200	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0
Nyabisika spring	Rainy	0	600	0	0	1600	0	0	0
	Dry	0	0	0	0	0	0	0	0
Rutshuru middle river	Rainy	0	2000	0	0	0	0	0	0
	Dry	0	1300	0	0	0	0	0	0
Rutshuru upstream river	Rainy	3300	1200	0	0	0	0	0	0
	Dry	0	0	2500	0	0	0	0	0
Rwankwi river	Rainy	1500	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	3000	0	0

Bacteriological analysis of different samples shows the presence of 5 bacterial species such as Klesbiella, Enterobacter, *Escherichia coli*, Hafnia and Serratia. Salmonella & Shigella and Vibrio cholerae were negative in all the water samples in Mikeno sector. Klesbiella was found in 8 sites while Enterobacter in 9 sites. *E. coli* was found in 4 sites were Hafnia and Serratia in one site. Compared to previous results of Karume *et al.*, (2016) and Bagalwa *et al.*, (2014), Escherichia coli was found in many sampling sites. Salmonella & Shigella and Vibrio cholerae were not found in Great Virunga by Karume *et al.*, (2016) but were found by Bagalwa *et al.*, (2014). The presence of faecal materials in water originates from human and animals and high erosion rate near the water body, which are the reasons of the water pollution of different bacteria in water sampling. These high counts of bacterial could be due to high levels of organic matter and faecal material present in the water and around the sources. This was also observed in Lagoon in Cameroun (Akoachere *et al.*, 2008). In the major tributary rivers in the watershed of Lake Eduard, *E. coli*, *Vibrio cholera* and Klesbiella were recorded (Bagalwa *et al.*, 2014). The presence of coliforms in water is a warning signal that more dangerous bacteria may be present. Diseases resulting from ingestion of pathogens in contaminated water have the greatest public health impact worldwide. Presence of faecal coliforms or *E. coli* is used as an indicator for the presence of any of the waterborne pathogens (Bengania *et al.*, 2015).

Compared the bacteriological aspect, the dry season was higher in bacteria. High values of bacteria were found during the dry season and specifics one as Klesbiella.

Bacteriological analysis of different samples shows the presence of 5 species of bacteria such as Klesbiella, Enterobacter, *Escherichia coli*, Hafnia and Serratia. Only 2 sites (Kamira source 1 and Kanyamarebe source) were exempt of different form of bacteria. Klesbiella was found in 7 sites while Enterobacter in 8 sites. E. coli was found in Kamira source site, Hafnia in Kabareberebe source and Serratia in Kanyamarebe River. Compared to previous sample in 2015 only 2 sites were contaminated with *E. coli* (Indata river and Rwanki), this period, high number of sampling site was contaminated. These high counts of bacterial could be due to high levels of organic matter and fecal material present in the water and around the sources. This was also observed in Lagoon in Cameroun (Akoachere *et al.*, 2008). In the major Tributaries Rivers in the watershed of Lake Eduard, *E. coli*, *Vibrio cholera* and Klesbiella were recorded (Bagalwa *et al.*, 2014). *E. coli* is the most common in the samples in this study while Klesbiella is the most in the present study. *Vibrio cholera*, salmonella and shigella bacteria were not found in the samples during this sampling period.

3.3. Macroinvertebrate Assemblage

Macroinvertebrate collected in different rivers in the Mikeno sector during the year 2015 and 2016 in the rainy and dry seasons are presented in table 4.

Table 4: Macroinvertebrate Taxa in the Rivers in the Mikeno Sector during the Two Years (2015 and 2016)

Taxa	Indata River		Rwankwi River		Indata River (Chaux)		Rutshuru River (Middle)		Rutshuru River (Inlet)		Kihwera River		Kanyamarebe River		Nyabisika River		Kamira River	
	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015
Isogenus modesta					2													
Baetis sp			4								4		2				3	4
Stenonema frontale											7							
Afronurus sp																	1	
Polycentropus sp											2							
Chinama eterima													1					
Hydropsyche simulans			2							2	2						4	1
Glossosoma sp											2							
Speudogrion sp				2														
Coenagrion sp			5		3			4	1	8							1	
Tachopteryx thorey								6										
Chloroperlinae (NI)				1						1								
Progomphus obtectus				2														
Aeschna sp				2	1													
Corydalus cornutus																	1	
Eristalis sp						1												
Chironomus tentas						7		6				6						9
Culex albipes			1															
Culex sp											1							
Simulium sp											10	9		3			5	2
Psychoda sp												3	5					2
Odontomyia cincta											1							
Palpomyia sp											1			3				3
Tabanus sp												1		1				
Gerris lacustris		1	6		8	1	3				12							
Hydrometra sp			1															
Ranatra fusca								4										
Pelocoris femoratus								3										
Scirtes sp			1															
Phanocerus clavicornis																	2	
Amphizoa lecontei						1												
Agyronecta aquatica	2			1		1												
Agyronecta sp															1			
Potamogeton sp			7	8	2				1								1	4
Palaemonetes sp						1												
Gordius sp		1	1															
Helobdella sp													8	1				

Macroinvertebrate sampling in the different rivers shows 3 classes of macroinvertebrates (insecta, nematoda and mollusca), 15 orders, 37 families and 41 species.

Rwanki River has the highest specific diversity (19 species) and Nyabisika has the lowest number of taxa during the sampling period. Some species were found in the 2 sampling periods in rainy or dry seasons (*Baetis sp*, *Simulium sp*, *Pschoda sp* and *Potamogeton sp*). The presence of tolerant taxa in some rivers shows that some rivers in the region still pristine. The macroinvertebrate assemblage collected in the period of study shows that the number of individual species in the rivers varied during the two years of study. This was probably due to chemical stressors (conductibility, dissolved oxygen, pH, total suspend solid), physical stressors (streambed stability, riparian vegetation) and biological stressors (native and non-native) as observed in other rivers in the world (Paretti and Robison, 2007).

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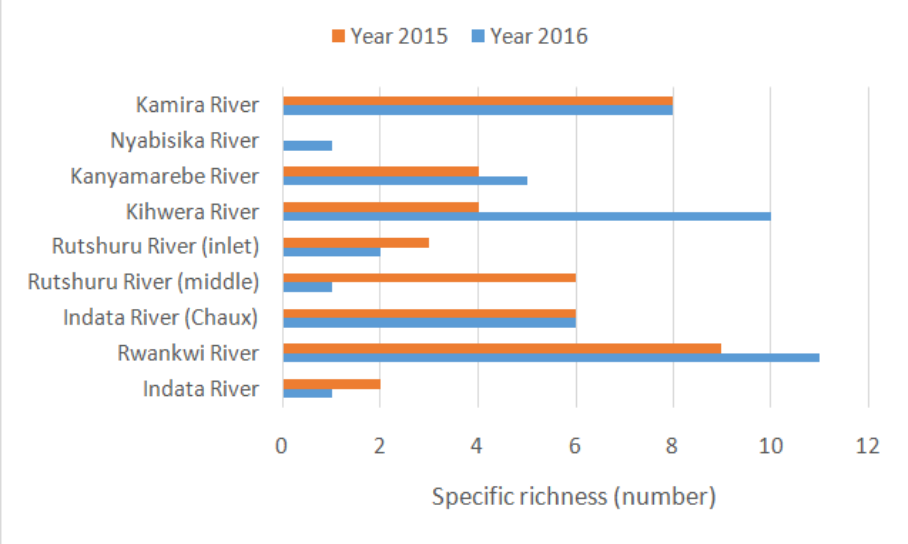

Figure 2: Specific Richness in Rivers Samping Sites During the Two Years 2015 and 2016

The specific richness is low compared to other studies in the tropical region (Bagalwa *et al.*, 2013) but it is comparable with the results in the Great region (Karume *et al.*, 2016). This low specific richness was due to the bad conditions of sampling in rain time when water flow was high and difficult for sampling at the riverbank. In rainy period the volume of water in the rivers was high and the sampling was difficult to realize. In the accessible sites anthropogenic activities reduced the vegetation on the riverbanks, which causes water deterioration. Species diversity is positively

correlated with water quality. It was observed that the diversity of tropical aquatic ecosystems is severely threatened by anthropogenic activities (Haileselasie and Teferi, 2012).

4. CONCLUSIONS AND RECOMMENDATION

Water quality and quantity in rural area in many African countries remains a serious deal and a priority action. This study contributes to understand and evaluate the water quantity and quality in order to provide water of appropriate quality to various water users in Mikeno sector, Virunga landscape. The quality of water obtained from these sampling points is generally good to use for different domestic purposes.

In order to improve the quality of water in these landscapes, communities need to engage in watershed management practices such as soil and water conservation, to limit the amount of pollutants reaching the waterways. In addition, sanitation and health education of the communities need to be strengthened and urge them to use the latrines and thus reduce faecal contamination of the water sources.

The communities around the protected area systems need to be sensitized about the link between water resources and the protection of watersheds and how this influences livelihoods and human health. Incentives need to be given to communities that conserve watersheds and provide clean water to downstream communities. The incentives may be in the form of market-based approaches to conservation, such payment for water services. Commissioning and training of population in the region on water cleaning and water sanitation: Chlorination, filtration, boiling, etc., need to be given to the communities in the Mikeno Sector. Future macroinvertebrate studies in the ecoregion should examine long-term temporal variation in communities among site classifications, particularly when assessing impacts of a major perturbation.

5. ACKNOWLEDGEMENTS

The authors are thankful to the GVTC, for financial support. We are also grateful to all the technicians who helped in data analysis in the different laboratories at the Centre de Recherche en Sciences Naturelles de Lwiro.

REFERENCES

1. *Abida B. H., 2008. Study on the Quality of Water in Some Streams of Cauvery River. E-Journal of Chemistry, 5, (2): 377-384.*
2. *Ahipathi M.V., and Puttaiah, E.T., 2006. Ecological Characteristics of Vrishabhavathi River in Bangalore (India). Environmental Geology, 49: 1217-1222.*
3. *Ali M. M., Ali M. L., Islam M. S., Rahman M. Z., 2016. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environmental Nanotechnology, Monitoring & Management, 5, 27–35.*
4. *Akoachere J-F.T. K., Oben P. M., Mbivnjo B. S., Ndip L. M., Nkwelang G., and Ndip R. N., 2008. Bacterial indicators of pollution of the Douala lagoon, Cameroon: Public health implications. African Health Sciences, 8, 2, 85- 89.*
5. *APHA, 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edition, American Public Health Association, Washington DC.*
6. *APHA, 2006. Standard Methods for Examination of Water and Waste-water. 21st Edn., American Public Health Association, Washington, DC., USA.*
7. *Armitage, P.D., Moss, D., Wright, J.F., and Furse, M.T., 1983. The performance of a new biological water quality score based on macroinvertebrates over a wide range of unpolluted running-water sites. Water Res. 17, 333–347.*

8. *Azrina M.Z., Yap C.K., Rahim Ismail A., Ismail, and Tan S.G., 2006. Anthropogenic impacts on the distribution A.and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. Ecotoxicology and Environmental Safety 64, 337–347*

9. *Bagalwa M., Majaliwa J.G.M., Mushagalusa N., and Karume K., 2013. Estimation of transported pollutant load from small urban Kahuwa river micro-catchment in Lake Kivu, Democratic Republic of Congo. Journal of Environment Science and Engineering B 2, 460 – 472.*

10. *Bagalwa M., Yalire M., Balole E., and Karume K., 2014. A Preliminary Assessment of Physico Chemical and Bacteriological Characteristics of Lake Edward and Majors Tributaries Rivers, Democratic Republic of Congo. Scholars Academic Journal of Biosciences (SAJB), 2, 3, 236-245*

11. *Bagalwa M., Ziririane N., Pauls S. U., Karume K., Ngera M., Bisimwa M., and Mushagalusa N. G., 2012. Aspects of the Physico-Chemical Characteristics of Rivers in Kahuzi-Biega National Park, Democratic Republic of Congo. Journal of Environmental Protection, 3, 1590-1595.*

12. *Bartram J., and Balance R., 1996. Water Quality Monitoring: A Practical Guide to the Design of Freshwater Quality Studies and Monitoring Programmes. Chapman & Hall, London.*

13. *Bengamia B., Adadji M. H., Ramdari M., and Kihal M. 2015. Bacteriological quality of drinking water originated from groundwater in Beni-Abbees area (South West Algeria). African Journal of Agricultural research, 01, 53, 4844 – 4849.*

14. *Bogan M. T., and Lytle D. A., 2007. Seasonal flow variation allows 'time-sharing' by disparate aquatic insect communities in montane desert streams. Freshwater Biol., 52, 2, 290-304.*

15. *Dalai T. K., Rengarajan R., and Patel P. P., 2004. Sediment geochemistry of the Yamuna river systems in the Himalaya: Implications to weathering and transport. Geochem. J., 38, 441- 453.*

16. *Faith N., 2006. Water Quality Trends in the Eerste River, Western Cape, 1990- 2005. A mini thesis submitted in partial fulfilment of the requirements for the degree of Magister Scientiae, Integrated Water Resources Management in the Faculty of Natural Science, University of the Western Cape. pp. 41.*

17. *FEPA, 1991. Guidelines and Standards for Environmental Pollution Control in Nigeria, Federal Environmental Protection Agency Regulation 1991 on Pollution Abatement in Industries and Facilities Generated Wastes. 78, 42, 38 p.*

18. *Gangwara R. K., Khareb P., Singha J., and Singh A. P., 2012. Assessment of physico-chemical properties of water: River Ramganga at Bareilly, U.P. Journal of Chemical and Pharmaceutical Research, 4, 9, 4231 - 4234.*

19. *Gaur V. K., Gupta S. K., Pandey S. D., Gopal K., and MishraV., 2005. Distribution of heavy metals in sediment and water of river Gomti., 102, 1, 419-433.*

20. *Golterman H. L., Clymo R. S. and Ohnstad M. A. M., 1978. Methods for physical and chemical analysis of fresh waters. Blackel scientific publication, London, UK. 213pp.*

21. *Gupta N., Nafees S. M., Jain M. K., and Kalpana S., 2011. Physico-chemical assessment of water quality of river Chambal in Kota city area of Rajasthan state (India), 4, 2, 686-692.*

22. *Gupta S., Bhatnagar M., and Jain R., 2003. Physico-chemical characteristics and analysis of Fe and Zn in tube well water and sewage water of Bikaner City. Asian j. chem. 15: 727.*

23. *Haileselasie T. H. and Teferi M., 2012. Influence of water quality on the diversity and distribution of macroinvertebrates in Hiwane Second Order Stream, Northern Ethiopia. Research Journal of Environmental and Earth Sciences, 4, 4, 475-481.*

24. *Hassan A. S., Bashir D., Hayatu J. M., and Mohammed I. U., 2016. The influence of drinking water quality on health and food security in Taraba State, Nigeria. European Journal of Earth and Environment, 3, 2, 1-16.*

25. *ISO., 1986. Water quality-Determination of Cobalt, Nickel, Copper, Zinc, Cadmium and Lead-Flame Atomic Absorption Spectrometric Methods. In International Standard (Vol. 1986). Geneva: International Organisation of Standardisation.*

26. *Jayaseelan T., Damodaran R. and Mani P., 2015. Analysis of physico-chemical properties of waste water effluents from textile industrial area of Tirupur, Tamil Nadu, India. Acta Biomedica Scientia. 2, 2, 84-89*

27. *Jena V., Gupta S., and Matic N., 2013. Assessment of Kharoon River water quality at Raipur by physicochemical parameters analysis. Asian J. Exp. Biol. Sci., 4, 1, 79-83*

28. *Kapembo M.L., Laffite A., Bokolo M. K., Mbanga A. L., Maya-Vangua M. M., and Poté J., 2016. Evaluation of water quality from sub-urban shallow wells under tropical conditions according to the seasonal variation, Bumbu, Kinshasa, Democratic Republic of the Congo. Exposure and Health, 8, 4, 487–496. http://dx.doi.org/10.1007/s12403-016-0213*

29. *Karume, K., Bagalwa, M., Yalire, M., Kazi, K., Bagula, E.M., Bitariho, R., Nahayo, D., Kasangaki, A. and Byamukama, J., 2016. Hydrological Systems in the Greater Virunga Landscape: Water Quality around Mikeno Sector. Journal of Water Resource and Protection, 8, 382-396. http://dx.doi.org/ 10.4236/jwarp.2016.83032*

30. *Lytle D. A., Bogan M. T., and Finn D. S., 2008. Evolution of aquatic insect behaviours across a gradient of disturbance predictability. Proc R Soc., 275, 1633, 453-462.*

31. *Poddar, A., & Das, S. K. (2018). Microbiological studies of hot springs in India: a review. Archives of microbiology, 200(1), 1-18.*

32. *Mariadoss S., and Ricardo A., 2015. Water Quality Assessment of Piatua River Using Macroinvertebrates in Puyo, Pastaza, Ecuador. American Journal of Life Sciences, 3, 3, 167-174. doi: 10.11648/j.ajls.20150303.17*

33. *Mbalassa M., Bagalwa M., Nshombo M., and Kateyo M., 2014. Assessment of physicochemical parameters in relation with fish ecology in Ishasha River and Lake Edward, Albertine Rift Valley, East Africa. International Journal of Current Microbiology and Applied Sciences, 3, 6, 230-244.*

34. *Mesa L. M., 2012. Interannual and Seasonal Variability of Macroinvertebrates in Monsoonal Climate Streams. Braz. Arch. Biol. Technol., 55, 3, 403-410.*

35. *Micha J. C., Moiset J. L., 1982. Evaluation biologique de la pollution de ruisseaux et rivières par les macroinvertébrés aquatiques, Probio Revue, 5.1.142p.*

36. *Michaud J. P. and Wierenga M., 2005. Estimating Discharge and Stream Flows. A Guide for Sand and Gravel Operators. Ecology Publication Number 05-10-070, 37 p.*

37. *Nedeau E. J., Merritt R. W., and Kaufman M. G., 2003. The effect of an industrial effluent on an urban stream benthic community: water quality vs. habitat quality. Environ. Pollut. 123, 1–13.*

38. *Needham J. G., and Needham P. R., 1962. A guide to the study of freshwater biology. Holden day, Inc, San Francisco.*

39. *Nienie A. B., Sivalingam P., Laffite A., Ngelinkoto P., Otamonga J.P., Matand A., Mulaji C. K., Mubedi J. I., Mpiana P. T., and Poté J., 2017. Seasonal variability of water quality by physicochemical indexes and traceable metals in suburban area in Kikwit, Democratic Republic of the Congo. International Soil and Water Conservation Research, 5, 2, 158-161. http://dx.doi.org/10.1016/j.iswcr.2017.04.004*

40. *Nola M., Nougang M. E., Noah Ewoti O. V., Moungang L. M., Krier F., and Chihib N. E., 2013. Detection of pathogenic Escherichia coli strains in groundwater in the Yaoundé region (Cameroon, Central Africa). Water and Environment Journal, 27, 3, 328–337. http://dx.doi.org/10.1111/j.1747-6593.2012.00349.x.*

41. *Olapande O. J., 2011. Trace metal pollution and physicochemical characteristics of Lake Kivu, Rwanda. Global Journal of Environmental Research, 5, 2, 56 – 64.*

42. *Olapande O. J., and Omitoyin B. O., 2012. Anthropogenic pollution impact on physico-chemical characteristics of Lake Kivu, Rwanda. Scholarly Peer Reviewed, 12, 6517-6536.*

43. *Olivier L. and Scheiderman M., 1956. Method for estimation of the density of aquatic snail population. Exp. Parasitol., 5: 109-117.*

44. *Paretti N. V., and Robison A. T., 2007. Ecological assessment of streams in the Little Colorado River Watershed, Arizona, 42p.*

45. *Ramdani A., Djellouli H. M., Aït Yala N., Taleb S., Benghalem A., Mahi C., and Khadraoui A., 2012. Physicochemical water quality in some regions of Southern Algeria and pretreatment prediction. Procedia Engineering 33, 335–339.*

46. *Ravisankar N., and Poogothai S., 2008. A study of ground water quality in Tsunami affected areas of Sirkazhi taluk, Nagapattinam district, Tamil Nadu, India. Sci. Tsunami Hazards, 27, 1, 47-55.*

47. *Sangpal R. R., Kulkarni U. D., and Nandurkar Y. M., 2011. An assessment of the physico-chemical properties to study the pollution potential of Ujjani Reservoir, Solapur District, India. ARPN Journal of Agricultural and Biological Science, 6, 3, 34 -38.*

48. *SCA (Standing Committee of Analysts) (2002) The Microbiology of Drinking Water. Part 1-Water Quality and Public Health. Methods for the Examination of Waters and Associated Materials. Environment Agency.*

49. *Shah M. C., Shilpkar P., and Sharma S., 2007. Correlation, Regression Study on Physico-chemical parameters and water quality assessment of ground water of Mansa Taluka in Gujarat, Asian J Chem. 19, 5, 3449-3454.*

50. *Shetty S., Tharavathy N. C., Lobo R. O., and Shafakatullah N., 2013. Seasonal variation in the physico-chemical characteristics along the upstream of Tungabhadra River, Western Ghats, India. International Journal of Plant, Animal and Environmental Sciences. 3, 1, 242 – 246.*

51. *Srivastava A., Kumar R., Gupta V., Agarwal G., Srivastava S., and Singh I., 2011. Water quality assessment of Ramganga River at Moradabad by Physico-Chemical Parameters Analysis. VSRD-TNTJ, 2, 3, 119-127.*

52. *Srivastava R.K., and Sinha A.K., 1996. Water quality of the river Gangaat Phaphamau (Allahabad): Effect of mass bathing during Mahakumb. Envtal. Tox. Water quality, 11, 1, 1-5.*

53. *UNECE, 1994. Standard Statistical Classification of Surface Freshwater Quality for the Maintenance of Aquatic Life. In: Readings in International Environment Statistics, United Nations Economic Commission for Europe, United Nations, New York and Geneva.*

54. *USEPA, 1997. Manual on Monitoring Water Quality. EPA 841-B-97-003.*

55. *Uwadiae R. E., Oni O., Egue O. E., Idowu T., Ezekwe F. E., Afor A., Sotomi T., and Mayungbe A., 2012. Patterns and determinants of benthic macroinvertebrate functional assemblages: function-environment interrelationship in a lagoon ecosystem. World Journal of Biological Research, 5, 2, 67 – 73.*

56. *Wetzel, R.G. and Likens, G.E., 2000. Limnological Analysis. Springer, Berlin, 429 p.*

57. *WHO, 2004. Guidelines for drinking-water quality (3rd ed.): Recommendations. World Health Organization, Geneva, 1.*

58. *WHO, 2011. Guidelines for drinking-water quality (4th edition, 541 pp). Geneva, Switzerland.*

59. *Wiens J. A., 1986. Spatial scale and temporal variation in studies of Shrub steppe birds. In: Diamond J., Case T.J., editors. Community Ecology. New York, NY: Harper and Row; pp154-172.*

60. *Xu H.S., Xu Z.X., Wu W., and Tang F.F., 2012. Assessment and Spatiotemporal Variation Analysis of Water Quality in the Zhang weinan River Basin, China. Procedia Environmental Sciences, 13, 1641 – 1652.*

61. *Ye L., Li D. F., Tang T., Chu X. D., and Cai Q. H., 2003. Spatial distribution of water quality in Xiangxi River, China. Chinese Journal of Applied Ecology; 14, 1959-1962.*